Chapter

Biological Waste Management

Muhammad Sajid, Ayesha Akram, Syeda Fatima Sajjad, Tehmina Siddique and Muhammad Arshad

Abstract

Biological waste management is an important aspect of environmental sustainability that requires proper disposal and treatment of biological waste produced from different sources. Biological waste is waste that comes from biological processes including wastes from plants, animals, hospitals, household, and municipal solid waste (MSW). Biological waste management involves the collection of waste from waste-producing sources, transport, processing, disposal, or recycling. The biological waste management technologies include composting, incineration, landfill, anaerobic digestion, and bioconversion to produce biofuels, i.e., bioethanol, biodiesel, biogas, etc. Urbanization, industrialization, changing lifestyles, and consumption patterns of the public have resulted in increased production of biological waste worldwide. Production of biological waste is affecting soil health and biodiversity, crop productivity in case of discharge of industrial liquid waste into the fields, and human health, and contributes to global warming and climate change. Furthermore, every year, approximately one-third of the food produced is lost from the food chain as waste, resulting in increasing hunger, economic loss, inflation, and inequality among people. Hence, biological waste needs proper treatment to conserve the environment, and the bioconversion of waste to produce renewable sources of energy like biogas, biodiesel, and bioethanol will result in the reduction of emission of greenhouse gases.

Keywords: biowaste, MSW, incineration, anaerobic digestion, biogas, 3R's

1. Introduction

Biowaste or biological waste is a waste that comes from a wide range of sources including animal wastes, plant wastes, domestic wastes, commercial wastes, ashes, biomedical wastes, construction wastes, radioactive wastes, and industrial solid and liquid wastes [1, 2]. Biological waste management is the collection of waste from the waste generation source, transport, processing, disposal or recycling, and proper monitoring of waste materials in case of hazardous nature of wastes, e.g., radioactive wastes, as shown in **Figure 1** [2]. Biological waste management is gaining attention worldwide as the amount of waste has been steadily increasing due to the increasing human population, changes in their lifestyles and consumption patterns, urbanization, food grain production, economic growth, and industrialization [1–3]. Approximately one-third of the food produced is lost every year from the food chain as waste, resulting in increasing hunger, economic loss, inflation, and inequality among people [4, 5]. Moreover, the generation of biological waste is affecting soil

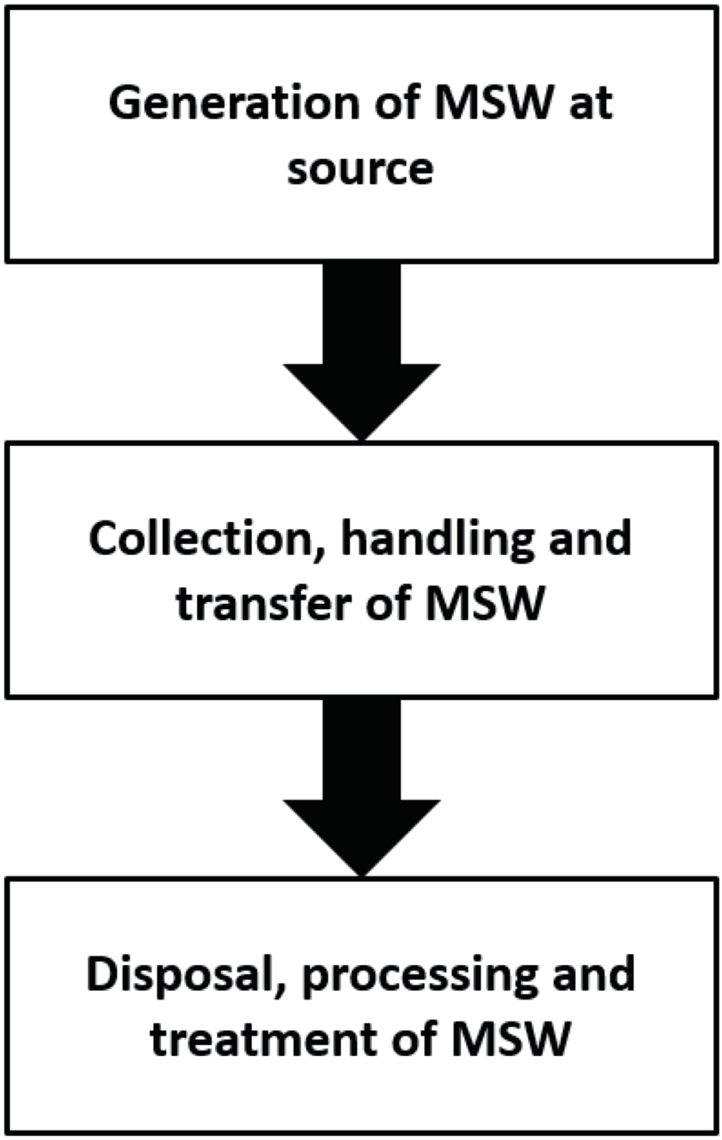

Figure 1.
General steps of a classical MSW management process.

health, soil biodiversity, and crop productivity, as in the case of the discharge of industrial liquid waste into the fields, human health, and contributes to global warming and climate change [1].

Municipal solid waste (MSW), one of the contributors to increasing environmental pollution, is defined as waste containing organic and inorganic wastes from residential or household, commercial, and industrial sources [6]. Random urbanization, industrialization, and economic expansion have resulted in increased generation of municipal solid waste (MSW) per head. According to the recent report by the Central Pollution Control Board (CPCB) 2019-2020, currently, about 1.2 kg of solid waste per capita per day, i.e., 3 billion tons per year, are generated by 3 billion residents of the world cities [1]. Due to poor infrastructure, financial constraints, and poor regulatory

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policies in developing countries like India, a huge percentage of street garbage is left unprocessed, and thus, they are major contributors to increasing global warming and climate change [7].

For the sustainable development of human society and environmental conservation, biological waste should be managed or treated properly. The waste produced can be recycled or recovered to produce renewable sources of energy like biodiesel, biogas, and biofuels and to recover other nutrients. The waste material can be recycled by the processes of physical reprocessing, biological reprocessing, and energy recovery [2]. The world is shifting from non-renewable energy sources, i.e., fossil fuels, to renewable sources of energy, i.e., biogas, bioethanol, and biodiesel. Burning of fossil fuels releases huge amount of greenhouse gases into the atmosphere and is major threat to the environment and thus human health, while the burning of renewable sources of energy is eco-friendly [8]. Bioconversion of solid waste into energy sources not only reduces the waste concentration from the environment but is also a good step toward the utilization of the waste in a better way. Almost 1.3 billion tons of municipal solid waste was collected worldwide in 2013 and may be expected to increase to 2.2 billion tons by 2025. Most of this is disposed of in landfills, where they may contribute to soil contamination and produce gases such as methane and carbon dioxide that cause global warming. Biological methods (such as anaerobic digestion, esterification, and fermentation) and physiochemical methods (such as gasification, incineration, and landfills) are currently in practice to transform waste into energy [2, 9]. For example, biodiesel is produced by the esterification reaction of restaurant oils and bioalcohols from organic wastes using fermentation. The waste management hierarchy is shown in **Figure 2**, which shows that prevention from

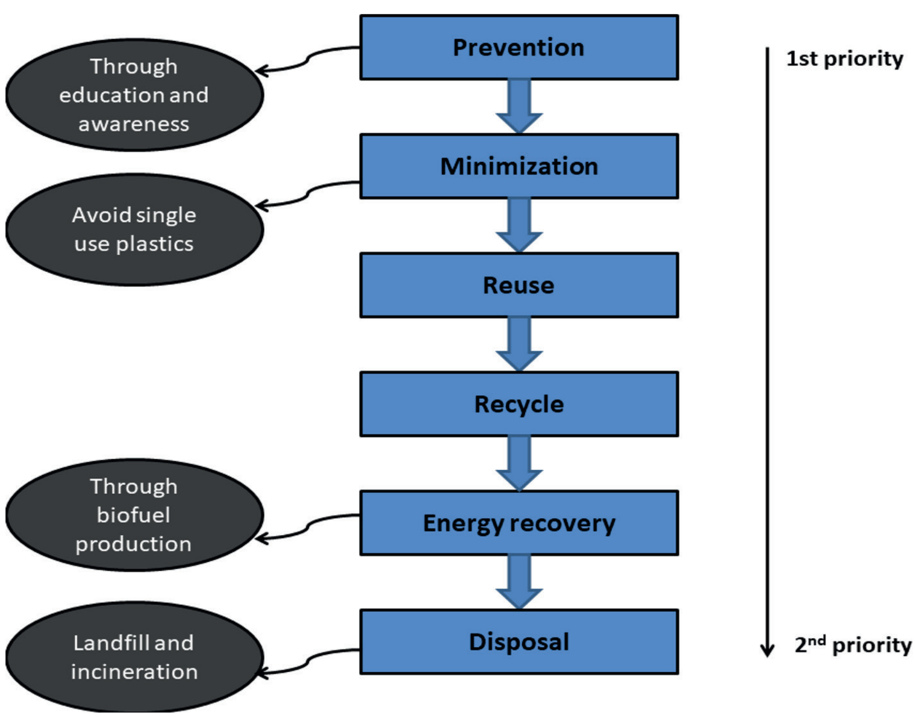

Figure 2.
Waste management hierarchy.

creating waste should be our first priority, while the disposal of waste should be the second or last choice.

The biological waste management technologies are composting, incineration, landfilling, anaerobic digestion, disposal methods, and bioconversion for biofuel production [2, 4]. Composting is an aerobic conversion of organic waste such as fruits and vegetable scraps into nutrient-rich soil through natural decomposition that can be used to nourish plants [10]. Incineration is the combustion of waste material. A landfill is a container-like body for the disposal of wastes. Anaerobic digestion is a process employed to convert the organic material directly into biogas carried out by a group of microorganisms in the absence of oxygen [9].

Managing biowaste should be cost-effective in order to protect the environment and improve living standards. Secondly, education and awareness regarding waste management are very important from a global perspective of pollution control and resource management [2]. The concept of a sustainable environment should be introduced to the youth to reduce the amount of waste that is discharged into the environment by reducing the amount of waste generated, i.e., amount of waste discharged ≤ amount of waste generated. Burning of waste in open fires should be avoided to prevent human health and environmental risks. Furthermore, a detailed overview of the types and sources of biological wastes, along with their management methods, are discussed below.

2. Classification of biological waste on the basis of its sources

On the basis of sources of waste, they are generally classified into (1) domestic wastes, (2) animal wastes, (3) biomedical or medical wastes, (4) commercial wastes, (5) ashes, (6) construction wastes, (7) industrial solid wastes, (8) sewer, (9) hazardous wastes, (10) agricultural residues, (11) biodegradable wastes, and (12) non-biodegradable wastes [2] as some are mentioned in **Figure 3**.

Domestic wastes include household wastes that contain fabrics, plastic, paper, vegetable and fruit scraps, polythene, ceramics, etc. A case study was done in Dhanbad, India, to predict household solid waste production. According to PIB (Press Information Bureau, Government of India), in 2016, 165 million tons of waste

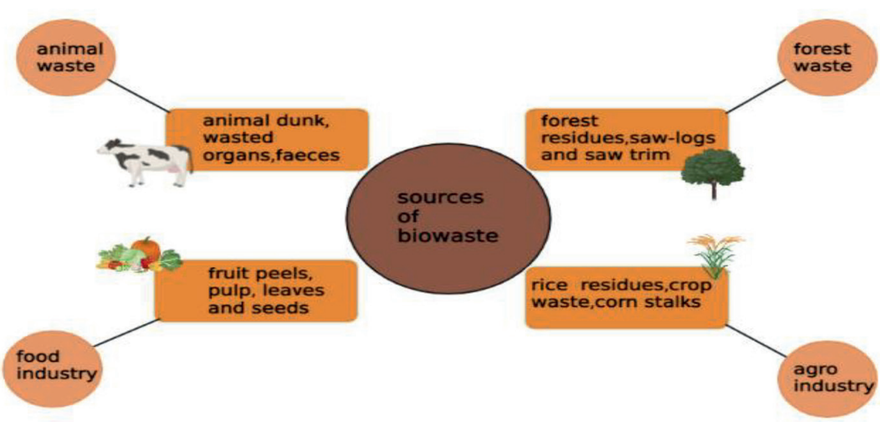

Figure 3.
Different sources of biowaste.

were produced yearly, which is continually increasing [11]. *Animal or livestock wastes* include livestock manure. According to a report by EPA in 2015, about 55 billion tons of animal waste is generated by animal categories [12]. *Medical or biomedical* waste is generated in the diagnosis, treatment, or immunization of animals and human beings [13]. According to a study, total medical waste generated by healthcare facilities was 28.8% in 2011 [14]. *Commercial wastes* include packing materials, polythene, spoiled goods, printer papers, and vegetable and meat remains that are generated in commercial places like shops, offices, etc. A case study was done in Austria in 2000 to predict the commercial waste generation from different sources. This study tells us that about 20–50% of the waste comes from commercial sources [15]. *Ashes* are generated as waste from the burning of wood, coal, fossil fuels, etc. *Construction wastes* generated at the construction sites, e.g., cement, roofing materials, concrete, metal roads, bricks, etc. About 44% of the waste contributes to construction waste, according to a case study to minimize construction waste generation in 2017 [16]. *Industrial waste* is generated by various small or large-scale industries like the textile industry, food industry, pharmaceutical industry, cigarette factories, etc. According to a report by FAO in 2015, between 20 and 50% of food is wasted and produced for human consumption [17]. *Sewer* from the sewerage poses various health hazards to the public. *Hazardous wastes* include radioactive wastes, which may come from the hospitals or energy sectors [18]. *Agriculture residues* include crop residue, husks, straws, wood, etc. *Biodegradable* (can be decomposed) wastes include kitchen garbage, animal dung, etc. *Non-biodegradable* (cannot be decomposed) wastes include plastics, glass, etc.

3. Waste management methods

3.1 Disposal methods

For the management of large quantities of a diverse range of biological wastes in an energy-efficient and environment-friendly way, there should be proper disposal. The proper disposing of the waste require the keen examination of the nature of the wastes from their generation sources such as the raw materials for their manufacture, manufacturing process, their hazardous nature, possible reuse of items, and proper disposal of the wastes in general [2]. An integrated waste management system is key to the proper management of biological waste. For integrated waste management, the concept of maximum output consists of 3Rs (reduce, reuse, and recycle) followed by landfill and gas to energy and waste to energy conversion. Traditionally, solid and liquid wastes are disposed of in landfills and through incineration.

3.1.1 Landfill

Disposal through landfill is the most inexpensive waste management method [19]. A landfill is more likely to be a tightly sealed storage container, deprived of air and water, where organic wastes are degraded very slowly with the help of microorganisms—the decomposing bacteria [20]. It has been estimated in 2016 that approximately 16% of all the dumped municipal solid waste (MSW) is incinerated while the remaining is disposed of in landfills [21]. The decomposition of organic waste in landfills is accompanied by a series of stages, each of which is marked by the increasing or decreasing population of specific decomposing bacteria and the production and consumption of certain metabolic products. In the first stage, the aerobic bacteria remove oxygen from the waste. This step usually takes less than a week. In the second stage, a diverse population of hydrolytic and fermentative bacteria acts on the waste and hydrolyzes polymers such as cellulose, proteins, lipids, and hemicellulose into simple monomers such as amino acids, simple soluble sugars, long-chain carboxylic acids, glycerol, etc. The second stage is also termed the anaerobic acid stage. These metabolic byproducts are the components for the generation of biogas and biofuels [2, 4].

Depending on the type of waste, as mentioned in the sectioned named classification of waste, the location and disposal facilities of landfills vary. We have classes, i.e., Class 1 disposes of waste in soil, Class 2 disposes of construction and renovation waste, Class 3 disposes of MSW, Class 4 disposes of commercial as well as industrial waste, Classes 5 and 6 dispose of underground disposal of hazardous waste, i.e., radioactive waste and medical waste, etc. [6, 22].

Effective management of the waste has become a major environmental and social concern. The medical wastes from hospitals can be very infectious as they contain expired drugs, surgical dressings, plastic syringes, blood, etc. [13, 23]. Hence, proper medical waste management is required before it may affect public health or become a source of infectious diseases.

It has been observed that waste decomposition in landfills leads to the emission of greenhouse gases such as methane CH_4 and carbon dioxide CO_2, which, when released into the environment, causes pollution [24, 25]. These gases are produced when MSW is degraded aerobically and anaerobically during chemical, biological, and thermal reactions in the landfills. CH_4 contributes 1–2% of greenhouse gases [26]. According to a study by United States Environmental Protection Agency (USEPA) in 2020 in the USA, landfills are the third largest contributor of CH_4 in the atmosphere. Thus, if there is more concentration of combustible CH_4 gas in the composition of landfill gases, there is a potential hazard of accidental explosions and fires on the site [6]. Furthermore, a case study was done in India in 2017 to analyze the contaminants released from the closed MSW landfill container. The contaminants containing the heavy metals As, Hg, Pb, and Mg^+ were contaminating the groundwater, soil, and surface water. Drinking water is also get contaminated, causing human health problems after drinking, as can be seen in **Figure 4** [27].

Although disposal of through landfills is the most inexpensive waste management option, it still has some associated problems. The contact of landfill leachates to the surrounding environment can create a threat to public health and nature. The methods developed for the treatment of landfill leachates are classified as physical, biological, and chemical, which are often used in combination in order to improve the efficiency of the treatment process [28]. Biological treatment methods can be aerobic, anaerobic, and anoxic and are widely used for the removal of biodegradable compounds from the leachates. For the removal of non-biodegradable substrates from the landfill leachates, physical and chemical methods are used, and they provide us with high nutrient levels. Furthermore, pretreatment methods are also used to improve the biological treatability of the leachates. EPA (provincial environmental agencies and Environmental Protection Acts) in Canada, USEPA (state environmental agencies and the US Environmental Protection Agency in the United States, Landfill Allowance Trading Scheme in the United Kingdom, Scottish Environmental Protection Agency in Scotland, Northern Ireland Environmental Agency in Northern Ireland and Landfill in the European Union are some of the government agencies which are regulating the management of landfills worldwide).

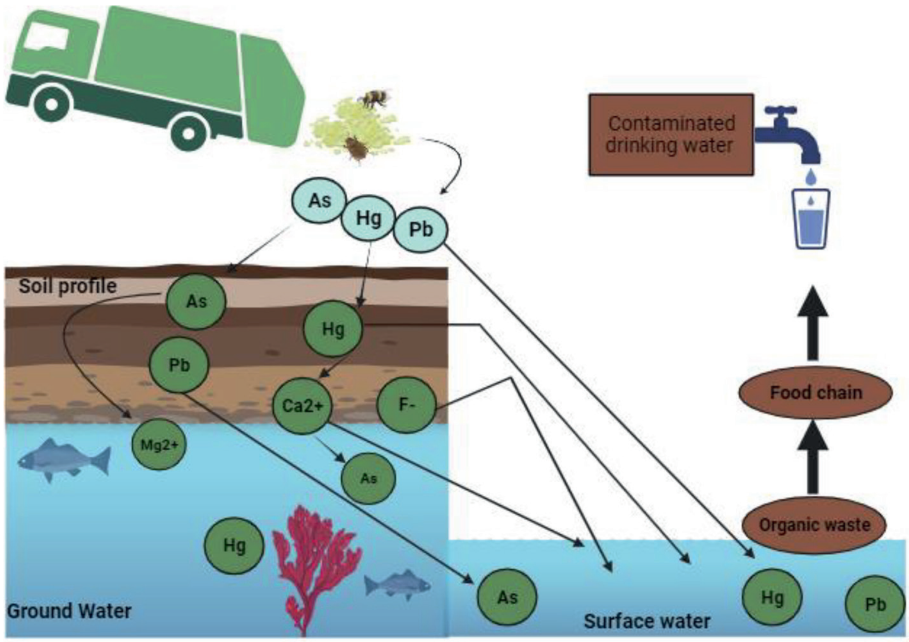

Figure 4.
Contaminants in the form of heavy metals released from the MSW landfill site.

3.1.2 Incineration

Incineration is another waste disposal method involving the combustion of waste material under high temperatures. It is also sometimes referred as "thermal treatment." An incinerator is typically designed, built, and operated at specific conditions where the waste material is burnt at high temperature in the presence of oxygen and energy is recovered from combustion [29]. Combustion of waste in the incinerators produces heat, which can be used to recover energy as seen in **Figure 5**. It is used to

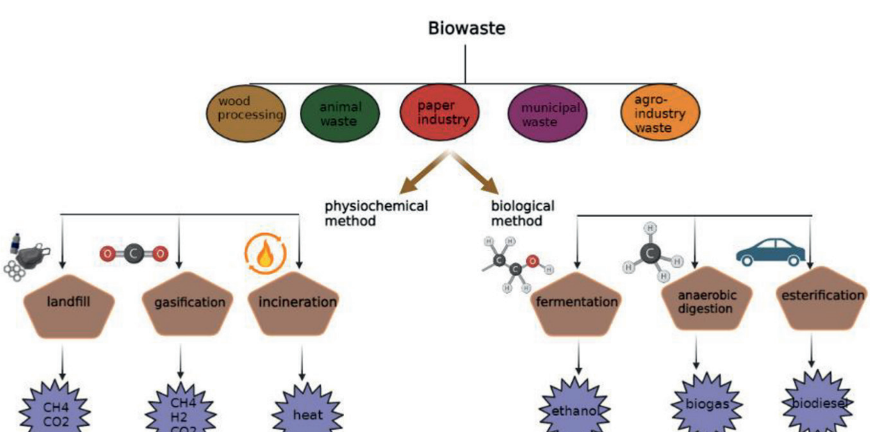

Figure 5.
Production of bioenergy from different biowastes sources.

dispose of solid, gaseous, and liquid waste. Biomedical wastes are also incinerated to prevent health hazards to the public. It also avoids the production of CH_4 gas. It is carried out on a small scale by individuals as well as on a large scale by industries. Japan, China, and the United States are using incinerators to treat the waste to produce electricity [30, 31].

Although incineration is better than landfill disposal, especially with respect to the management of hazardous wastes, this method is considered controversial due to the emission of pollutant gases, which contribute to increasing environmental pollution. The incomplete combustion of organic matter in the incinerator results in the emission of carbon monoxide along with high content of inorganic compounds and carbon compounds [32, 33]. Toxic metals, dioxins, and furan are also released from the incinerators, affecting human health [31]. Inhalation of airborne pollutants causes respiratory problems and consuming contaminated food and water also poses serious health issues in humans [34]. Cancer and respiratory problems, congenital disorders, hormonal defects, and imbalance in the sex ratio are some of the impacts of incineration gases on human life. At the same time, its impact on the environment can be seen in the form of global warming, acidification of soil, smog formation, ozone depletion, aquatic toxicity, and eutrophication in the form of algal blooms formation [35]. A case study was done in Wuhan (China) in 2015 to evaluate the waste incineration plants to determine the impact on the environment, human health, and the site [36].

4. Biowastes as biofuels

4.1 Agriculture residues

Agriculture residues are generally categorized into field residues and process residues. The material left in the fields after the harvesting of the crop is field residue [2]. For example, stalks, stems, seed pods, and leaves. The material left after the processing of the crop into a usable resource contributes to process residue. For example, husks, seeds, roots, bagasse, etc., are used as components of biofuel generation, while others are used as animal feed and for soil management. For example, cereal straw is used as feed, garden mulch, and animal bedding, and the majority of it is burned into the soil. Field burning is generally practiced to dispose of straw, but now many countries are imposing bans on this traditional practice to avoid pollution generated. Likewise, corn Stover can be converted into biofuels as it has the potential for direct burning [33]. Through gasification, rice husk can be converted into fuel of uniform quality. Woody crops (poplar) and tropical grasses (elephant grass) are gaining more attention from energy crop companies due to their suitability (cellulose: lignin) for subsequent processing as energy crops.

Agriculture waste or crop residues are generally converted into biofuels by biochemical and thermochemical conversion technologies and are shown schematically in **Figure 6**. The thermochemical technologies can be combustion, gasification, pyrolysis, and hydrothermal liquefaction, while biochemical methods include enzymatic hydrolysis, anaerobic digestion, and microbial fermentation. In addition to these, sometimes transesterification, a chemical method, is used to convert the biomasses [37]. Combustion is a process in which biomasses are burnt in the presence of excess oxygen to convert them into thermal energy [38]. In a case study in Pakistan in 2016, it was showed that utilizing 70% of rice husk residues by combustion generated 1328 GWh of electricity annually. Using rice husk residues as a source

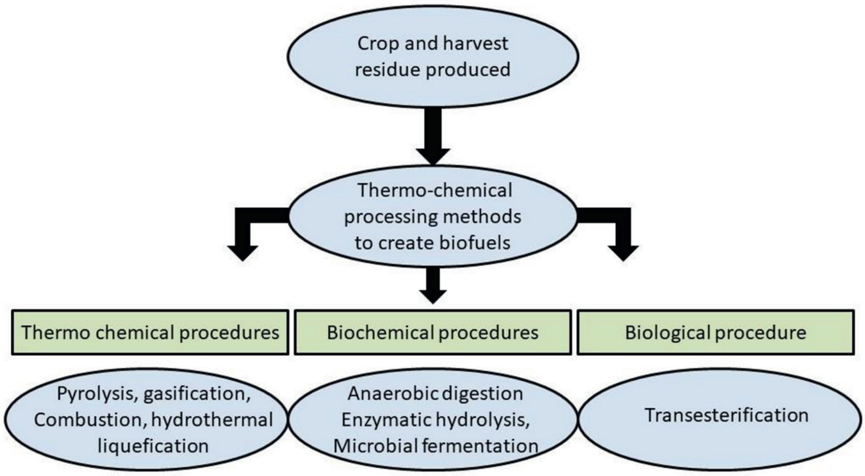

Figure 6.
Conversion techniques of agricultural residues into biofuels.

of energy, there is a great reduction in methane consumption and carbon dioxide emissions, and the provision of jobs in energy sector will reduce unemployment to some extent [39]. Gasification is a thermochemical conversion process in which we obtain a gaseous mixture of biomasses in the form of methane (CH_4), hydrogen (H_2), carbon dioxide (CO_2), and carbon monoxide (CO) in the presence of may be oxygen, steam, or a mixture of above-mentioned gases [38, 40]. In a case study in Malaysia in 2014, waste of oil palm was used to get the hydrogen to use it as a fuel by gasification process [41]. Burning of hydrogen does not produce greenhouse gases and can be used efficiently for electricity generation such as in hydrogen fuel cells [42]. Pyrolysis is a thermochemical decomposition occurring in the absence of oxygen at an increased temperature, usually at 400°C. An intermediate product, a liquid bio-oil, is produced and further processed into petrol, gasoline, diesel, or other fuels. Studies show that rice straw, rice husk, maize straw, and wheat straw are thermochemically converted into biofuels using pyrolysis [43, 44].

Enzymatic hydrolysis, a biochemical approach, utilizes glucose from agricultural residues and ferments it into ethanol. Under optimum pH and temperature conditions, enzymes permit yeast to produce ethanol in a fermentation reaction. This process is eco-friendly and reduces air pollution [45]. Anaerobic digestion is the breakdown of waste with the help of a group of microorganisms without oxygen [46, 47]. With transesterification, biodiesel from vegetable oil and animal fats can be obtained, which can be used as an alternative to petroleum diesel [48]. Overall, using agricultural residues as a source of biofuels reduces the emission of greenhouse gases, thus mitigating air pollution, but there is a need to work more on them to explore more crop residues to use them as a renewable source of energy thus will able to prevent them from degradation and from causing soil and air pollution.

4.2 Paper and pulp industry waste

The wastes left behind in the paper and pulp industry can be used in the biofuel production process [2]. For example, pulp mill sludge, when disposed of in landfills, degrades to methane gas, which contributes to the greenhouse effect. By using it in

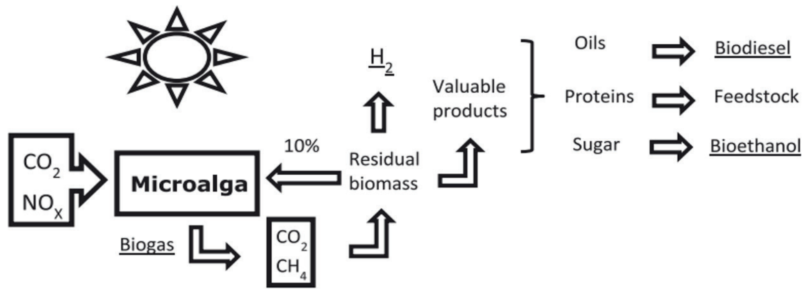

Figure 7.
Microalga is a source of biofuels (biogas, biodiesel, and bioethanol) and feedstock [53].

biofuel production, contamination of the land and the water can be prevented. Black liquor, another byproduct, can be combusted to produce energy in the paper mill, and electricity can be generated from the extra energy. Black liquor has a high energy content due to dissolved lignin. Almost 300–350 million tons of waste is produced by the world's paper and pulp industry, but only a small portion of it is recycled, and the rest causes pollution, i.e., land pollution and water pollution, and blocks the water passages and gutters [49, 50]. Thermochemical and biochemical conversion techniques are frequently used to convert waste paper and pulp into bioethanol, biodiesel, and petroleum products [51]. Waste paper contains 50–73% of cellulose content, which can be enzymatically degraded to get biofuels [52].

4.3 Algae

The photosynthetic organisms, i.e., microalgae, are acquiring great attention for fuel use. In some algae, up to 50% of their dry mass contains oil content [2]. Thus, scientists are working on the production of algae oil for biodiesel as well as other types of biofuels, as can be seen in **Figure 7**. It has been estimated that diatom algae can produce 40 tons of oil/ha/year, 7–31 times more than the oil production from the best-performing vegetable oil palm plant and 200 times more than the soybean plant, according to a report by NREL (National Renewable Energy Laboratory) in 1998 [54]. This capability of producing high oil content can be used as an alternative renewable energy resource. However, the separation of algae from water is highly costly; there has not been any commercial undertaking so far.

5. Biogas from waste

Anaerobic digestion (AD) is a process employed in the production of biogas from biowaste, as mentioned in **Figure 2**. AD is the collective process of the breakdown of biodegradable waste with the help of a group of microorganisms, specifically in the absence of oxygen [4, 55, 56]. Biogas is a mixture of gases, mainly methane and carbon dioxide, with trace amount of other gases [2]. It can be used as a fuel for engines, boilers, gas turbines, or for manufacturing other chemicals after final gas cleanup. The anaerobic digestion of biowaste takes place in four basic steps: (1) hydrolysis, (2) acidogenesis, (3) acetogenesis, and (4) methanogenesis. In the first step, microbes produce enzymes named hydrolases that convert the complex components of the biowaste into simpler molecules like sugars, amino acids, fatty acids, etc. [57].

In the second step, the acidogenic bacteria further ferment these simple molecules into various volatile fatty acids (VFAs) and gaseous components (H_2 and CO_2). In the third step, acetogenic bacteria reduce these molecules into acetic acid. In the fourth and last step, methanogenic bacteria ferment the intermediate products of the various steps into methane, CO_2, and water [58]. The production of biogas from biowaste is gaining attention on a commercial scale. Germany is the largest producer of biogas in Europe, followed by Italy, the United Kingdom, France, and Switzerland [4]. Depending on the type and nature of the components in the biological waste, the yield of the biogas can be varied. For example, for pure cellulose, the biogas product contains 50% methane and 50% carbon dioxide. In case of mixed waste feedstock, methane percentage in biogas products will be 40–60% by volume. Fats and oils can provide us with a methane content of 70% [2].

The use of an anaerobic digestion (AD) approach to manage biowaste can not only help to solve waste management and energy problems but also generate revenue by providing side products. Furthermore, all types of biowaste (agro-industry, animal, MSW, and food) can be subjected to AD process. If we talk about the environmental problems associated with waste, air pollution, and water pollution are the two main environmental risks affecting public health. The increasing trend toward urbanization and rapid industrialization results in more consumption of non-renewable sources of energy [59]. This will not only result in the depletion of energy resources but also an additional step toward causing environmental pollution. More transportation causes more burning of fossil fuels like petrol, diesel, compressed natural gas (CNG), etc. Burning fossil fuels releases greenhouse gases such as oxides of sulfur, oxides of nitrogen, carbon dioxide, carbon monoxide, etc. [60]. Greenhouse gases cause global warming, i.e., a condition of increased temperature of the earth and climate change [61]. Water pollution is another problem which is caused by the waste. A case study in Malaysia showed that palm oil industries are a major contributor to water pollution [62]. The dissolved solids in effluent pollute the freshwater resources when they it gets enters into the rivers, streams, lakes and oceans affecting the marine life by making a layer of oil on the surface of water. The layer of oil on the surface of water trapped the light which comes from the sun, thus the photosynthetic activity of plants greatly reduces. Furthermore, bacteria utilizes the oxygen of the water, thus depletes the oxygen available for the marine life.

6. Conclusion

Biological waste which comes from different sources like households, plants, agriculture, paper pulp industry, hospitals, construction sites, animal waste, municipal solid waste (MSW), and industrial liquid and solid waste, need proper management and treatment to ensure a safe and clean environment. The treatment of biological waste through landfilling and incineration produces greenhouse gases. But, the recycling of biowaste and their bioconversion for the useful production of renewable energy sources like biogas can overcome the above-mentioned pollution problem. Usually, thermochemical, biochemical, and chemical conversion technologies are employed. Among them, combustion, pyrolysis, anaerobic digestion, and transesterification are mostly used to convert the biomasses into biofuels like biodiesel, bioethanol, and biogas, which are potential renewable sources of energy. Burning renewable sources of energy is clean and eco-friendly. Shifting toward renewable sources of energy from non-renewable sources such as converting biowaste into biofuels, will reduce environmental pollution and prevent complete depletion of non-renewable energy resources like petrol, natural gas CH_4, etc. Furthermore, electricity generation from biomasses is also a plus point toward increasing electricity units and decreasing electricity per unit cost. Hence, by properly disposing of and treating biological waste, we will ultimately achieve the goal of zero-waste societies.

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